MICROSTRUCTURAL AND COMPOSITIONAL RELATIONS OF GRANITOID CLASTS IN LUNAR BRECCIAS AT THE MICROMETER TO SUB-MICROMETER SCALE. R. Christoffersen[1], J. I. Simon[2], R.D. Mills[3], D. K. Ross[1,2] and M. Tappa[1,2], [1]Jacobs/JETS Contract, NASA Johnson Space Center, Mail Code XI2, Houston, TX 77058, USA (roy.christoffersen-1@nasa.gov), [2]Center for Isotope Cosmochemistry and Geochronology, NASA Johnson Space Center, Mail Code XI2, Houston, TX 77058, USA, [3]Department of Geological Sciences, University of North Carolina, Chapel Hill, NC 27599, USA.

Introduction: Lunar granitoid lithologies have long been of interest for the information they provide on processes leading to silicic melt compositions on the Moon [1,2]. The extraction of such melts over time affects the distribution and budget of incompatible materials (i.e., radiogenic heat producing elements and volatiles) of the lunar interior. We have recently shown that in addition to their high concentrations of incompatible lithophile elements, some granitoid clasts in lunar breccias have significant indigenous water contents in their alkali feldspars [3]. This raises the importance of lunar granitoid materials in the expanding search for mineralogic/petrologic hosts of indigenous lunar water-related species [4].

We are undertaking a detailed survey of the petrologic/mineralogical relations of granitoid clasts in lunar breccias to achieve a better understanding of the potential of these diverse assemblages as hosts for volatiles, and as candidates for additional isotope chronology studies. Our preliminary results reported here based on high-resolution field-emission SEM, EPMA and TEM studies uncover immense complexity in these materials at the micrometer to sub-micrometer scale that heretofore have not been fully documented.

Methods. Element mapping by X-ray energy dispersive (EDS) compositional spectrum imaging in a JEOL 7600F field-emission SEM at NASA JSC was used to identify granitoid clasts with appreciable modal alkali feldspar in allocated potions of lunar breccias 12013, 14303 and 15405. The overall petrologic and compositional relations of the diverse granitoid clast populations in these rocks have been reviewed by [1,2]. Follow-up detailed study of the individual clasts performed at JSC utilized detailed EDS element mapping and back-scatter electron (BSE) imaging on the JEOL 7600F, quantitative wavelength dispersive EPMA spot analyses on a JEOL JXA-8530F Ultraprobe, and analytical TEM characterization of focused ion beam (FIB)-sectioned samples using a JEOL 2500SE field-emission scanning transmission electron microscope (FE-STEM).

Results: The granitoid clasts can be broadly divided into granophyric/micrographic intergrowths of the type previously described by [5] and a more diverse population of complex intergrowths of plagioclase, Ba-enriched K-feldspar, ferroan low-Ca pyroxene and minor quartz (or other SiO_2 phase). Many of the latter clasts have lithologies relating them to the quartz monzodiorite (QMD)-monzogabbro clast suite discussed by [6,7]. It is from alkali feldspars in a QMD-type clasts that [3] recently reported significant indigenous water contents, making this category of clasts a particular focus of the current SEM and TEM characterization. Among the diversity of SEM scale microstructure and compositional relations in the QMD-type clasts are grains in which plagioclase and Ba-enriched K-feldspar form complexly intergrown microstructures, with a minor quartz (or other SiO_2 phase) in some cases. In a major subset of these, K-feldspar that is highly zoned in Ba-content (2.0-5.0 wt.% BaO) shows evidence of crystallizing from a residual melt mesostasis enclosed by earlier-crystallized plagioclase and pyroxene. A microstructurally more enigmatic set of clasts are those in which sub-equal modal proportions of ~An_{60} plagioclase and Ba-rich alkali feldspar form patchy to irregular intergrowths at the less than 10 µm scale (Fig. 1). We have previously reported [8] that FE-STEM characterization of a FIB section of one of these clasts reveals a microstructure suggestive of

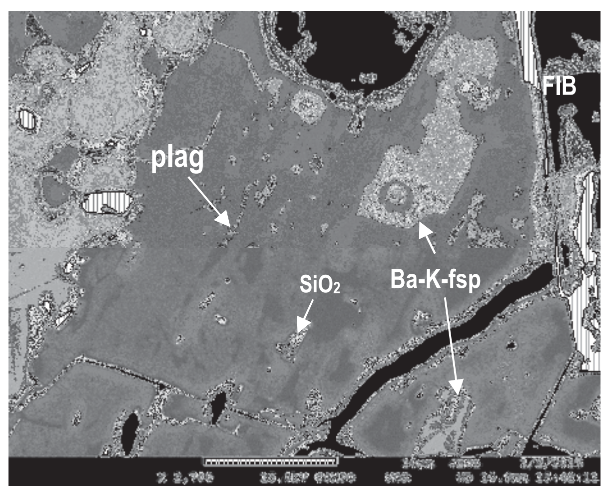

Fig. 1. SEM back-scattered electron image of intergrowth of Ba-rich alkali feldspar (bright regions), plagioclase (light gray) and minor quartz (dark gray) in a QMD-type granitoid clast from lunar breccia 14303. A portion of an area extracted for a TEM-FIB section is shown in the upper right.

simultaneous rapid crystallization of both feldspars likely also from a residual melt mesostasis. Paradoxically, however, the ~An_{60}-composition plagioclase shows evidence of sub-solidus development of either a Huttenlocher or *e*-plagioclase intergrowth consistent with a much slower cooled subsolidus history [8,9].

Discussion: As our survey of the microstructural and compositional relationships in granitoid clasts from 12013, 14303 and 15405 has progressed, we continue to find assemblages whose microstructures are suggestive of rapid crystallization from quickly cooled melts. This includes relationships in both the micrographic granophyritic clasts, as well as the fine-scale Ba-enriched K-feldspar and plagioclase intergrowths. The possibility that some of these clast assemblages are derived from alkali-enriched precursor feldspars and silica re-processed by partial shock melting is a working hypothesis we are evaluating. This hypothesis is supported by the observation that some alkali-enriched assemblages appear to be derived from melts injected into fracture networks in shocked plagioclase (Fig. 2). An impact origin for the melts that generated the fine-scale Ba-enriched feldspar and plagioclase intergrowths is also not necessarily incompatible with slow subsolidus cooling given the possibility that the host breccia may have become a part of a deep ejecta blanket shortly after the alkali-bearing shock melt solidified. A shallow magmatic setting is, however, also possible as we have previously discussed [8]. Deciphering primary magmatic clasts from impact generated/modified clasts has significant bearing on how to interpret the isotopic data used for chronology, and deciphering melt sources and associated volatiles including water. Our microstructural approach appears to have great promise in making these distinctions.

References: [1] Wieczorek M. A. et al. (2006) Rev. Min. Geochem. 60, 221. [2] Seddio et al. (2013) Am. Min. 98, 1697. [3] Mills et al. (2014) 77th Met. Soc. Meeting. [4] Saal A. E. et al. (2008) Nature 454, 192. [5] Warren et al. (1982) LPS XII, 839. [6] Ryder G. (1976) EPSL 29, 255. [7] Jolliff B. L. et al (1999) Am. Min. 84, 821. [8] Mills R. et al. (2014) LPS 2014, # 1547. [9] Smith J. V. (1983) Rev. Min. 2, 223.

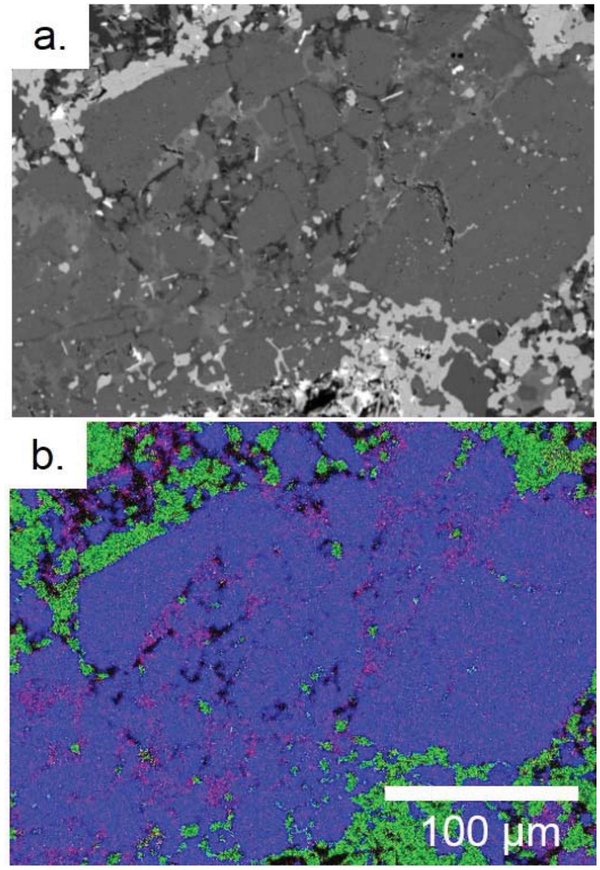

Fig. 2. SEM back-scattered electron image (a) and K (red)-Mg (green)-Al (blue) RGB element map (b) of K-bearing silicic material filling in a (shock) fracture network in plagioclase in a QMD-type clast in 12013.